CLINICAL APPLICATIONS OF INTRACARDIAC ECHOCARDIOGRAPHY IN INTERVENTIONAL PROCEDURES

M R M Jongbloed, M J Schalij, K Zeppenfeld, P V Oemrawsingh, E E van der Wall, J J Bax

Accurate knowledge of the anatomy of intracardiac structures is essential for the efficiency and safety of performing interventional procedures. Although fluoroscopy is an important aid while advancing catheters in the heart, it is not sufficient to supply accurate anatomical information on the position of veins, ridges, and septa in the heart. Furthermore radiation exposure forms a risk to both the patient and the operator.

Intracardiac echocardiography (ICE) is a promising technique for imaging of intracardiac structures, and may serve as an alternative for the transoesophageal approach,[1] which is semi-invasive and requires anaesthesiology. The introduction of ICE catheters with low frequencies allows accurate visualisation of intracardiac anatomical structures with an ultrasound catheter placed exclusively in the right side of the heart. This report focuses on the use of ICE in guiding percutaneous interventional procedures.

BASICS OF INTRACARDIAC ECHOCARDIOGRAPHY

History of two dimensional intracardiac ultrasound systems

The first application of ICE was done using mechanical ultrasound systems, which were introduced in the 1980s. These systems provided high resolution imaging, but because of the high frequency of the transducers (20–40 MHz), tissue penetration was only limited and anatomic intracardiac overviews could not be obtained. The subsequent development of lower frequency transducers allowed imaging of intracardiac structures, but these systems were still limited by the low steerability and over-the-wire design of the catheters.[2] The clinical use was improved by the development of flexible lower frequency transducers (9 MHz), but depth control of these catheters still was not sufficient to allow visualisation of the whole heart from the right side of the heart. In the 1990s, systems modified after transoesophageal echocardiographic probes were introduced. In these systems depth was improved by the use of lower frequencies (5 MHz). However, the large size of these transducers limited the clinical use. In recent years the development of steerable phased array ultrasound catheter systems with low frequency and Doppler qualities has expanded the clinical use of ICE.

What are the technical requirements?
Mechanical ultrasound tipped catheter

The mechanical ultrasound transducer tipped catheter (Clearview, Cardiovascular Imaging Systems Inc, Fremont, California, USA) can be used for both intravascular and intracardiac imaging. For intracardiac use, a 9 MHz single element transducer is incorporated in an 8 French catheter. A piezoelectric crystal is rotated at 1800 rpm in the radial dimension perpendicular to the catheter shaft, thus providing cross sectional images in a 360° radial plane. A sheath surrounding the imaging transducer is necessary to prevent contact of the imaging transducer with the cardiac wall. The ICE catheter needs to be filled with 3–5 ml sterile water before it is connected to the ultrasound machine (Boston Scientific Corp, San Jose, California, USA). Three dimensional reconstruction of the acquired data can be created.

Phased array ultrasound tipped catheter

This system uses a 10 French ultrasound catheter (Acunav Diagnostic Ultrasound Catheter, Acuson Corporation, Mountain View, California, USA), which is positioned in the right atrium (RA) or right ventricle (RV) via a femoral approach, through a 10 French introducer. The ultrasound catheter consists of a miniaturised 64 element, phased array transducer, which is incorporated in a single use catheter. The transducer scans in the longitudinal monoplane, providing a 90° sector image with tissue penetration of approximately 15 cm. Two planes of bidirectional steering (anterior–posterior and left–right, each in a direction of 160°) are possible by using a mechanism on the handle of the catheter. The high resolution multiple frequency transducer (5–10 MHz) allows tissue penetration enhancement, thus allowing depth control.

See end of article for authors' affiliations

Correspondence to:
Dr Jeroen J Bax, Department of Cardiology, Leiden University Medical Center, Albinusdreef 2, 2333 ZA Leiden, The Netherlands; jbax@knoware.nl

Abbreviations

▶ **ARVD/C:** arrhythmogenic right ventricular dysplasia/cardiomyopathy
▶ **ASD:** atrial septal defect
▶ **ICE:** intracardiac echocardiography
▶ **LA:** left atrium
▶ **LAA:** left atrial appendage
▶ **LV:** left ventricle
▶ **PFO:** patent foramen ovale
▶ **PV:** pulmonary vein
▶ **RA:** right atrium
▶ **RV:** right ventricle
▶ **TOE:** transoesophageal echocardiography
▶ **TTE:** transthoracic echocardiography
▶ **VT:** ventricular tachycardia

Measurements of haemodynamic and physiologic variables can be made using Doppler imaging. The catheter is connected to an ultrasound system (Acunav/Sequoia, Acuson Corp, Mountain View, California, USA).

Mechanical versus phased array ultrasound tipped catheter

Although the mechanical ultrasound systems can be used at a considerably lower cost compared to the phased array systems, there are several disadvantages as compared to the phased array transducers. Currently, no functional analysis can be performed with mechanical systems, due to the lack of colour and pulsed Doppler features. Since these systems use a single ultrasound frequency of 9 MHz and provide a limited radial depth of view (5 cm), imaging of left sided structures is not feasible with the ultrasound catheter placed in the right heart. This could increase the risk of thromboembolic complications when using the device for imaging of left sided structures. Furthermore, the design of the mechanical rotating catheter shaft, and the lack of an articulation mechanism at the handle, limits steering of the transducer and thus a dynamic view on intracardiac structures. In the remainder of the current report we mainly focus on the use of phased array ICE in guiding percutaneous interventional procedures.

Advantages and limitations of ICE during interventional procedures

In the past, if percutaneous interventions needed guiding, fluoroscopy, transthoracic echocardiography (TTE), or transoesophageal echocardiography (TOE) were used. The use of ICE has several advantages over these other techniques. No radiation is needed. In comparison to TOE, patient discomfort is less and general anaesthesia is not needed, allowing communication with the patient during the procedure. As compared to TTE, the transvenous access has the advantage that it is not necessary to position a transducer in a sterile field.

General advantages of ICE are the availability of direct online information on the position of catheters and devices, and the possibility of direct monitoring of acute procedure related complications (such as thrombus formation, pericardial effusion, etc).

Several limitations of ICE currently exist. First the considerable shaft size (10 French) and the lack of additional catheter features, such as ports for guidewires, therapeutic devices and pressure, form a limitation. Second, the phased array catheters are expensive and single use only. Third,

phased array ICE provides only monoplane image sections. Although this can partly be overcome by the steerability of the catheter, operators who are used to multiplane TOE transducers may have difficulty obtaining the same views. Moreover, no standard views for ICE are currently defined, as are available for TTE and TOE.

Which views can be obtained with ICE?

Using phased array ICE, views of all anatomic landmarks can be obtained with the ultrasound catheter positioned in either the RA or the RV. Although images quite similar to TOE can be obtained, the relatively "loose" position of the ultrasound probe in the heart may give the inexperienced operator a feeling of disorientation. To overcome this, structured introduction and steering/manipulation of the ultrasound tipped catheter can ultimately provide orientation, supported by recognition of the anatomical landmarks. The catheter is advanced via the femoral vein, into the middle part of the RA via the inferior caval vein, thus visualising the RA, tricuspid valve, and RV (fig 1A). This view with the catheter positioned in the middle of the RA can be used a "basic point of orientation", from which other views can be derived. Counterclockwise rotation with the catheter positioned in the superior part of the RA provides imaging of the terminal crest, whereas clockwise rotation of the catheter from the inferior RA provides a view of the Eustachian ridge with the tricuspid–caval isthmus (fig 1B); these are important target structures in atrial flutter ablation.

By turning the catheter around its axis (clockwise fashion as seen from the operator), imaging of the aortic valve, the right ventricular outflow tract, and the pulmonary artery is feasible (fig 1C). Long axis views of both aorta and pulmonary trunks can be imaged in the same plane, which is not feasible with TOE. By rotating the catheter clockwise from the low right atrium, a short axis view of the coronary sinus can be obtained, while left-to-right movements of the ICE catheter provide a long axis view of this structure (fig 1D, E). When the catheter is further rotated, the next anatomical structure important in interventional cardiology to be recognised is the atrial septum (important for septal puncture, see below). By counterclockwise movement of the catheter from this position, imaging of the left atrium (LA), mitral valve, and left ventricle (LV) is performed (fig 1F). By increasing the depth setting of the catheter with the transducer directed at the left atrial posterior wall, imaging of the left and right pulmonary veins and the left atrial appendage (LAA) is performed from the position of the atrial septum (important for pulmonary vein (PV) ablation, see below). As is it sometimes difficult to distinguish between the LAA and the left superior PV, Doppler capacities can be used to differentiate. Finally, by advancing the catheter into the RV, detailed imaging of the LV can be obtained. Both long and short axis views of the LV can be obtained (fig 1G, H).

CLINICAL APPLICATIONS

The clinical application of ICE in interventional procedures is listed in table 1.

Detection of intracardiac thrombus

Because of the risk of systemic embolism, evaluation of the presence of intracardiac thrombus before left sided procedures is mandatory. The risk of thromboembolic events is related to the presence of LA spontaneous contrast and an LAA peak emptying velocity $\leqslant$ 20 cm/s.[3] ICE can serve as an
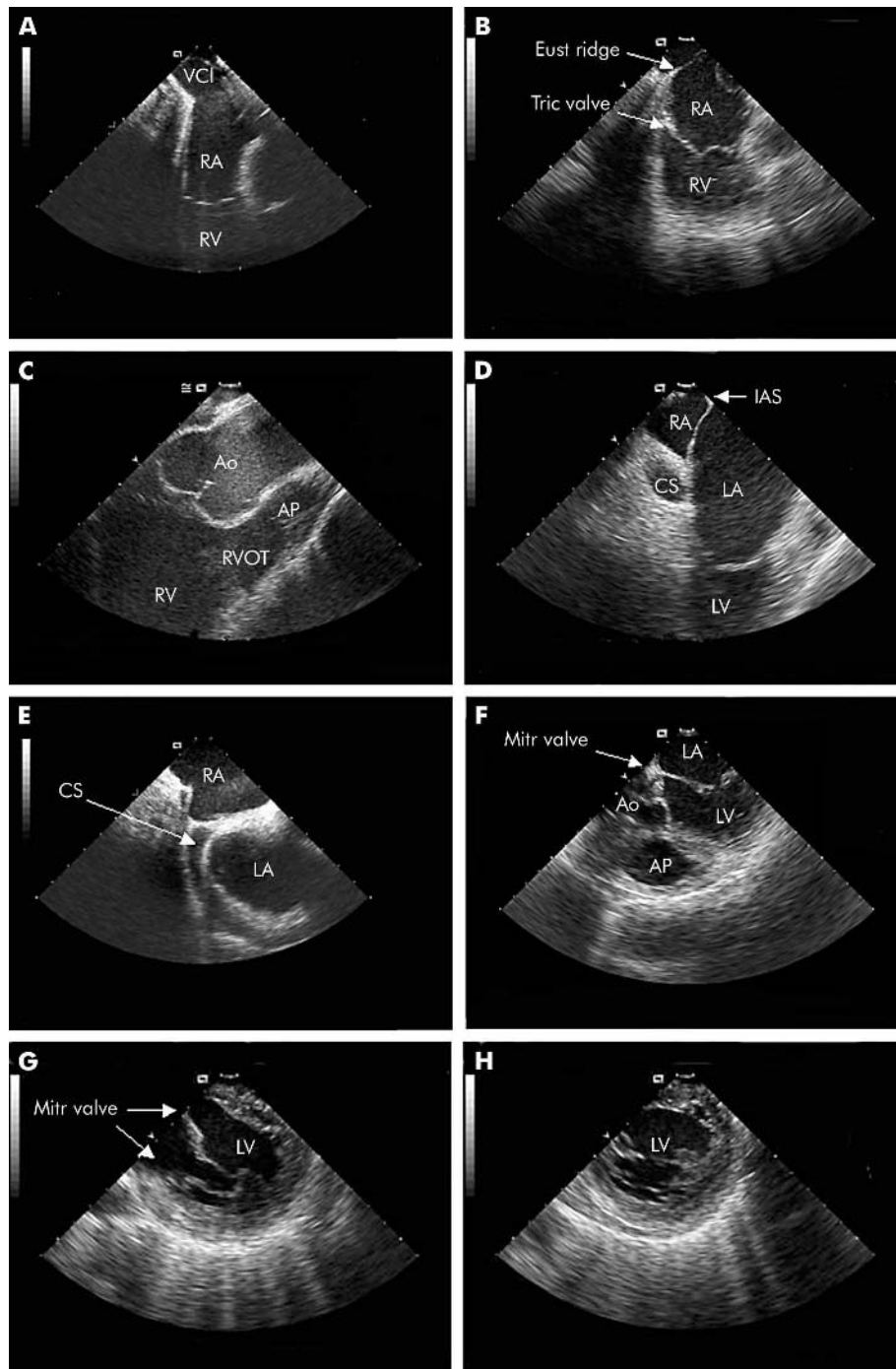
Figure 1 Different views obtained with the intracardiac echocardiography (ICE) transducer in either the right atrium or the right ventricle. See text for explanation of panels A–H. Ao, aorta; AP, pulmonary artery; CS, coronary sinus; Eust ridge, Eustachian ridge; IAS, interatrial septum; LA, left atrium; LV, left ventricle; Mitr valve, mitral valve; RA, right atrium; RV, right ventricle; RVOT, right ventricular outflow tract; Tric valve, tricuspid valve; VCI, inferior caval vein.

983

alternative for TOE assessment of LA and LAA function[4] (fig 2 A,B). Before left sided interventions, the LAA can be evaluated for the presence of thrombus (fig 2C).

The reported incidence of thromboembolic complications during left sided interventional procedures is approximately 2%,[5] possibly as high as 5% in patients with a history of transient ischaemic attacks.[6] Detection of intracardiac thrombus with ICE during left sided interventional procedures is discussed below (see PV ablation).

Transseptal puncture

Potential life threatening complications of transseptal puncture include aortic puncture, pericardial puncture or tampo-nade, systemic arterial embolism, and perforation of the inferior caval vein.[7] Accurate visualisation of the fossa ovalis reduces the risk of complications. Especially less experienced operators may find ICE a better imaging modality then fluoroscopy, by its ability to visualise accurately the target for transseptal puncture, the fossa ovalis.[8] The Valsalva man-oeuvre during injection of saline/contrast can be performed to reveal the presence of a patent foramen ovale (PFO) (fig 2D). In 10–20% a PFO is present, omitting the need for transseptal puncture (fig 2E). Positioning of the ultrasound catheter in the RA provides a clear vision of the interatrial septum, which consist of a thicker part, the limbus, and the remains of the primary atrial septum, the fossa ovalis, which is the safest

Table 1 Applications of intracardiac echocardiography (ICE) in interventional procedures

- ► Evaluation of intracardiac thrombus
- ► Transseptal puncture
- ► Atrial septal defect/patent foramen ovale closure
- ► Interventional electrophysiological procedures
  - – pulmonary vein ablation in patients with atrial fibrillation
  - – atrial flutter ablation
  - – ventricular tachycardia ablation
- ► Other applications
  - – diagnosis/biopsy of intracardiac masses
  - – balloon mitral valvuloplasty
  - – atrial appendage occlusion
  - – visualisation of coronary sinus

target for the transseptal puncture. During the puncture a Brockenbrough needle (DAIG Corp) is inserted via a transseptal sheath and dilator system and directed towards the fossa ovalis. The first sign of a stable contact of the transseptal dilator at the oval fossa, is "tenting" of the septum at this site (fig 2F). Successful puncture can be confirmed by the appearance of contrast in the LA after contrast injection. After withdrawal of the needle a mapping/ablation catheter can be positioned in the LA.

### Guidance of closure of atrial septal defect and patent foramen ovale

Percutaneous transcatheter device closure of atrial septal defect (ASD) and PFO has become a safe and efficient alternative to open heart surgery. Guidance of these procedures by TOE is standard practice and in recent years several studies have reported the feasibility and safety of ICE for guiding these procedures.[9][10] The closure of ASDs guided

by TOE, without use of fluoroscopy, has been described. However, although the procedure could be satisfactorily performed in most cases without prolongation of procedure times, patients needed to undergo extensive TOE, and significantly higher doses of sedation were used.[11] Especially for this application, when long and continuous echocardiography imaging is required, ICE reduces procedure and fluoroscopy times, does not require general anaesthesia, and is less discomforting than TOE.[9] During these procedures, ICE is used to determine the size and location of the defect in relation to cardiac anatomy and the presence of rims and septal remnants. Clear visualisation of the ASD/PFO, RA, LA, sizing balloon and closure device is feasible with a phased array catheter positioned in the RA (fig 3). Deployment of the device can be evaluated using ICE. Particularly when the remaining part of the septum is floppy, accurate evaluation of the stability of the closure device using Doppler dynamics is necessary before releasing the device.

### Guidance of interventional electrophysiology procedures
Pulmonary vein isolation procedures

The observation that ectopic foci originating in the PVs can initiate atrial fibrillation[12] has led to the development of percutaneous catheter ablation strategies aimed at ablation at the site of the PVs. Although results are promising, long procedure times and procedure related complications, such as PV stenosis, are still challenges for improvement. These issues are (in part) related to the fact that the ablation targets, the veno-atrial junctions and the PVs or their ostia, are not easily visualised using fluoroscopy. Furthermore, interindividual variations in PV anatomy occur, which may require adjustment of the ablation strategy. During PV ablation procedures, ICE can provide information on the individual PV anatomy, such as the number of PVs, the
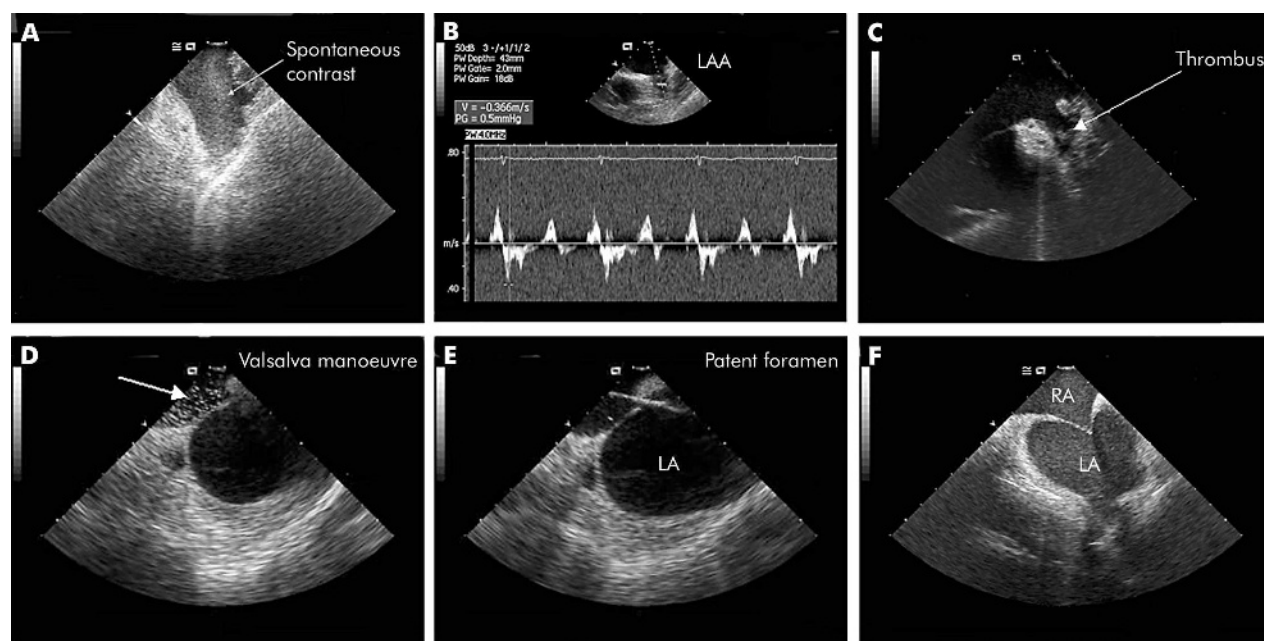
Figure 2 (A) Spontaneous contrast in the left atrial appendage (LAA), a risk factor for thrombus formation. (B) Function of the LAA can be determined with phased array ICE, using pulsed wave Doppler. (C) Thrombus in the LAA. (D) The Valsalva manoeuvre is performed before transseptal puncture to determine the presence of patent foramen ovale. Contrast bubbles can be observed in the right atrium (arrow). The lack of bubbles in the left atrium confirms the presence of a closed foramen. (E) The catheter is shifted through the septum through a patent foramen ovale (PFO). (F) Tenting of the septum caused by stable contact of the transseptal dilator/needle. LA, left atrium; RA: right atrium.
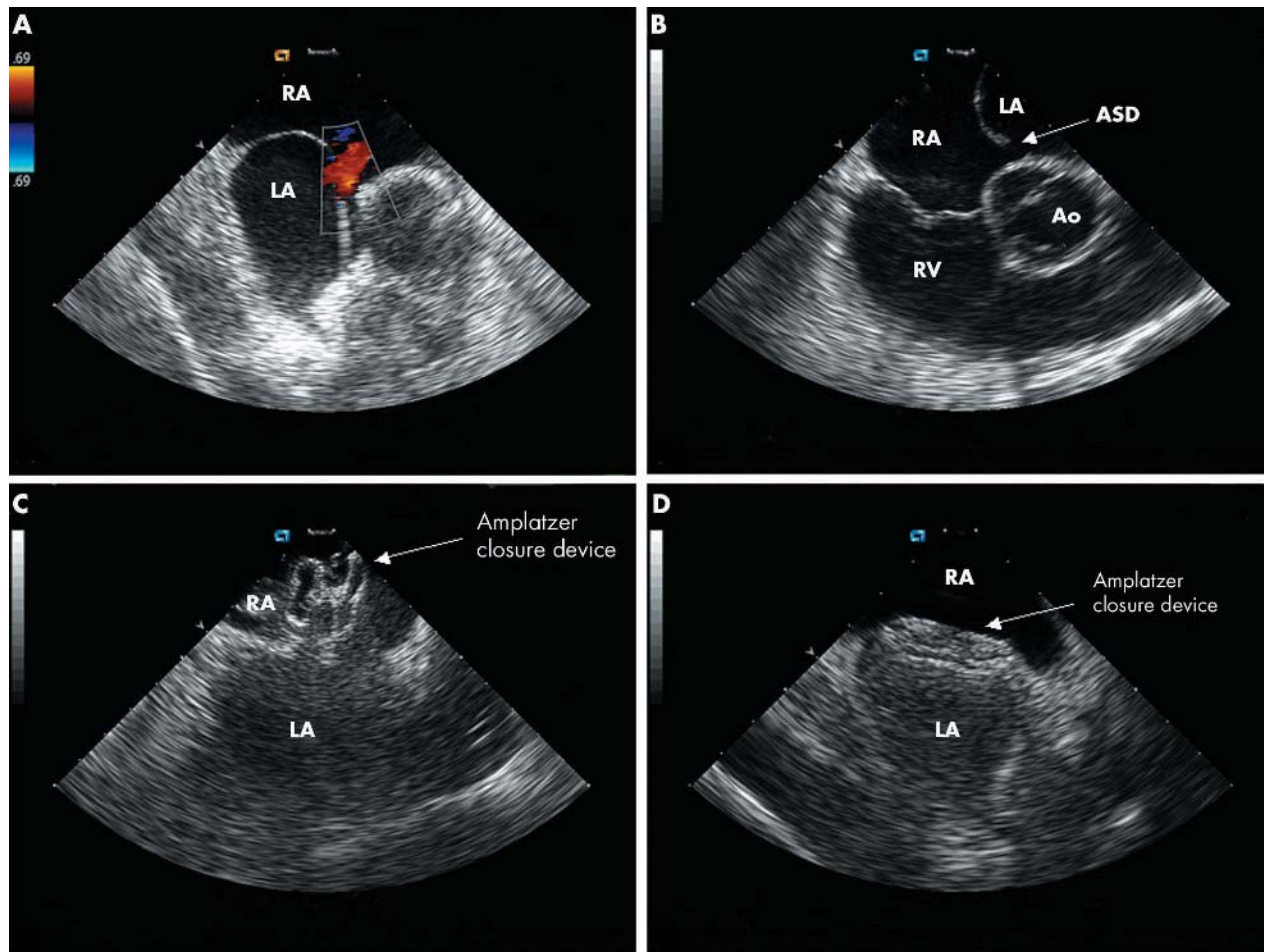
Figure 3 Closure of an atrial septal defect (ASD) under ICE guidance. (A) Colour Doppler demonstrating an ASD located in the inferior part of the atrial septum. (B) Relation of the ASD (arrow) to intracardiac structures. (C) Positioning of the Amplatzer closure device. (D) After several minutes, flattening of the closure device occurs. The device is positioned stable in between the right and left atria. Ao, aorta; LA, left atrium; RA, right atrium; RV, right ventricle.

presence of common ostia and of additional PVs, which may influence the ablation strategy in anatomical based isolation procedures[13] (fig 4A, B). Furthermore, ICE can be used to guide ablation catheters. In order to deliver optimal radiofrequency energy to the tissue, with a minimum amount of heat loss, a firm contact of the catheter tip with the myocardium must be established. It has been demonstrated that ICE can ensure adequate catheter tip–tissue contact in order to achieve transmural ablative lesions[14] and that the use of ICE improves the outcome.[15]

Another advantage of the use of ICE during these procedures is the ability to monitor the occurrence of acute complications. Potential complications of ablation at the site of the PVs are: PV stenosis, thromboembolic complications, and perforation with pericardial tamponade. Visualisation of micro-bubble formation is an important characteristic according to which power settings of the radiofrequency energy delivery can be adjusted,[15] to ensure maximal energy delivery at the lowest risk of PV stenosis (fig 4C). The occurrence of PV stenosis can be monitored by ICE by measuring the ostia of the PV and the systolic and diastolic flow velocities before and after catheter ablation. Both colour and pulse Doppler qualities can be used to demonstrate flow in the PV (fig 4D). Although usually increases in PV flow

velocities do not give significant symptoms and most patients seem to return to baseline flow characteristics within three months, cases have been reported of significant late PV stenosis/occlusion requiring PV stenting.[16] In general, however, mild to moderate acute changes in ostial diameters and haemodynamic parameters caused by acute oedema do not seem to have significant implications for the occurrence of late PV stenosis.[17] A recent report demonstrated the utility of intracardiac Doppler assessment of LA contractile function and reservoir function to predict the outcome of PV isolation.[18]

Finally, another important reason to consider the use of ICE during ablation procedures in the LA is that, despite anticoagulation, left atrial thrombus may occur during left atrial interventional procedures, usually by attachment of thrombus material to the stable positioned transseptal sheet and/or mapping catheter.[19]

Complex atrial flutter ablation

Electrophysiological mapping under guidance of ICE has been able to identify the cavo-tricuspid isthmus, Eustachian ridge, and the terminal crest as anatomical barriers in atrial flutter, which cannot be visualised using fluoroscopy.[20] Treatment of atrial flutter is performed by linear ablation at
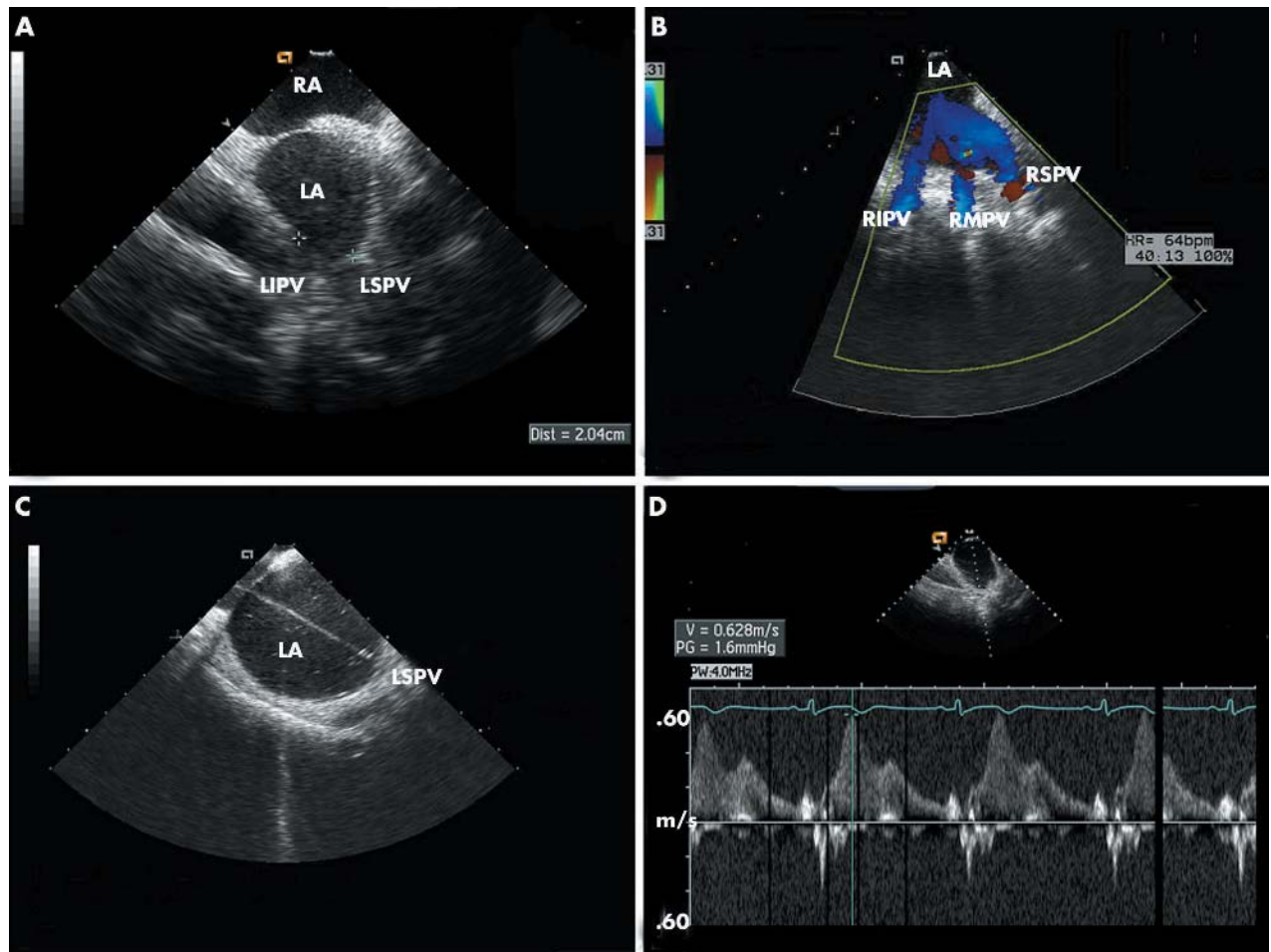
Figure 4 (A) Left PVs. There is a common ostium of the left PVs (diameter 2.04 cm). (B) Colour Doppler in the right PVs. Three right PVs are visible. (C) Ablation catheter at ostium of the left superior PV. Note the presence of microbubbles, indicating heat loss during ablation. (D) Pulsed wave Doppler measurements of flow in the PVs. LA, left atrium; LIPV, left inferior pulmonary vein; LSPV, left superior pulmonary vein; RA, right atrium; RSPV, right superior pulmonary vein; RMPV, right middle pulmonary vein; RIPV, right inferior pulmonary vein.
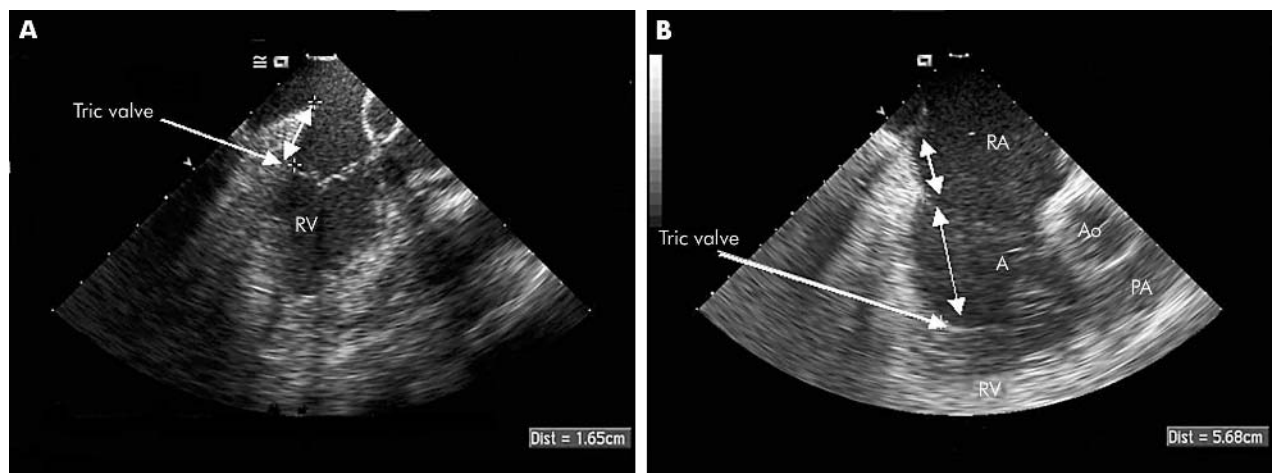
Figure 5 (A) The cavo-tricuspid isthmus (double arrow) demonstrated with ICE as the area in between the inferior caval vein and the tricuspid annulus. (B) Imaging of the cavo-tricuspid isthmus area in a patient with atrial flutter and Ebstein anomaly. Due to the low insertion of the tricuspid valve leaflet, part of the right ventricle is incorporated in the right atrium (A indicates ''atrialised'' right ventricle). Ao, aorta; PA, pulmonary artery; Tric valve, tricuspid valve; RA, right atrium; RV, right ventricle.
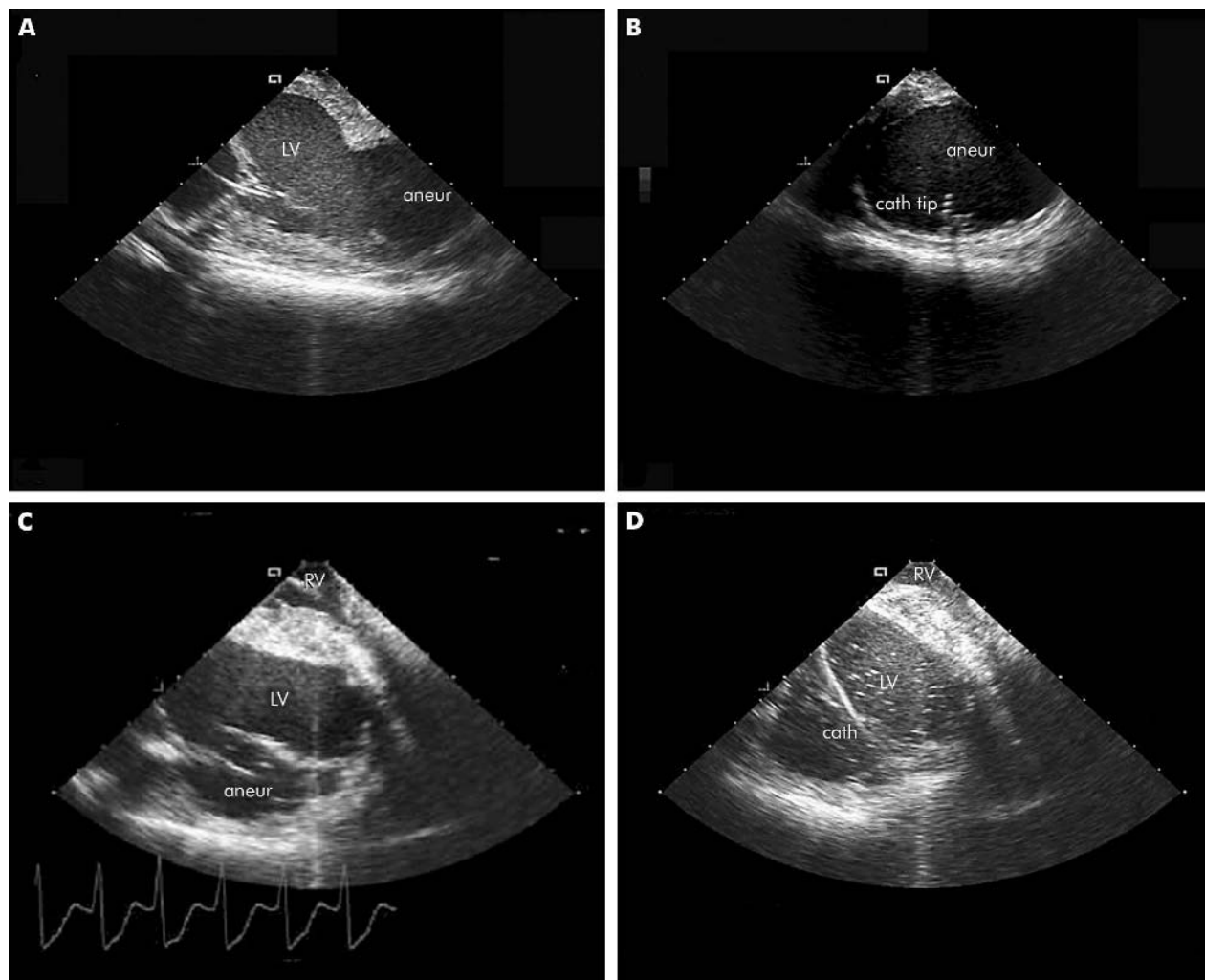
Figure 6 (A) Long axis view of the left ventricle (LV) and an apical LV aneurysm (aneur) in a patient with ventricular tachycardia. (B) Ablation catheter at the site of the LV aneurysm (short axis view), demonstrating perpendicular catheter tip–tissue contact. (C) Postero-basal LV aneurysm. (D) Microbubble formation during ablation, indicating heat loss. cath tip, catheter tip.

the site of the cavo-tricuspid isthmus, thus creating a line of lesions from the inferior caval vein towards the tricuspid valve annulus (fig 5A). Stable endocardial catheter contact can be confirmed by ICE.[21] Next to the presence of an atrial flutter circuit based on re-entry around right sided anatomical structures, atrial flutter based on a macro re-entrant circuit surrounding scar tissue can occur—for example, in patients treated for congenital heart disease. In these patients, anomalous cardiac anatomy often complicates the treatment of atrial flutter. Particularly in these patients, identification of intracardiac structures using ICE is useful. Fig 5B demonstrates the cavo-tricuspid isthmus area in a patient with Ebstein's anomaly. Due to the low insertion of the tricuspid value leaflet, part of the right ventricle is incorporated in the right atrium (length of the "atrialised" ventricle 5.68 cm).
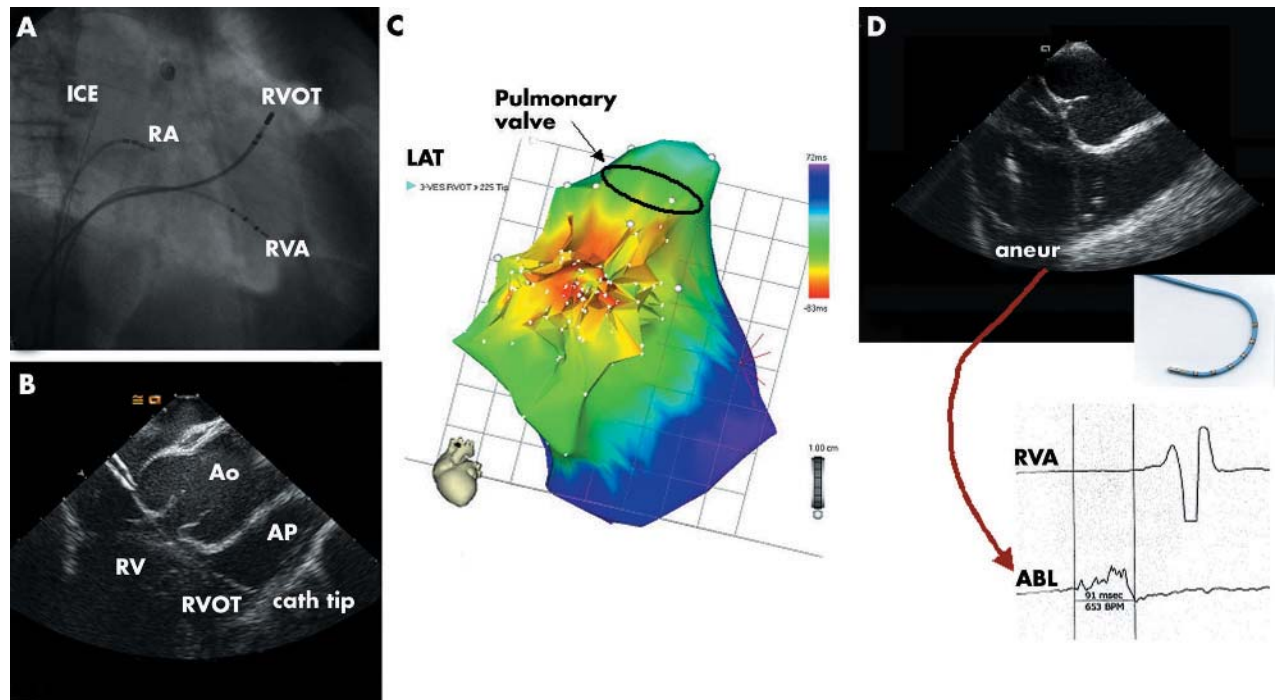
Ablation of ventricular tachycardia

Morphologically altered myocardium—for example, the presence of scar tissue or aneurysms after myocardial infarction, and multiple aneurysms as present in arrhythmogenic right ventricular dysplasia/cardiomyopathy (ARVD/C)—is prone to the formation of re-entrant circuits.

The majority of ventricular tachycardias (VTs), however, are secondary to ischaemic heart disease; arrhythmias originate either from extensive scars or ischaemic border zones after infarction. The regions with scar formation are frequently akinetic or dyskinetic (aneurysmatic), which can easily be visualised on ICE (fig 6).

Potential complications of VT ablations include thrombo-embolic events, valvar damage, perforation, and pericardial tamponade. ICE can be used to guide catheters and for continuous monitoring of complications during VT ablation procedures.[22 23] The ability of phased array ICE catheters to image left sided cardiac structures with the imaging catheter exclusively in the right heart is especially advantageous in patients with dilated ventricles, in order to evaluate the presence of intracardiac thrombus, without the need of arterial or transseptal puncture. Lamberti *et al*[24] have reported the use of ICE as an aid in establishing the position and stability of the ablation electrode in relation to the anatomic localisation of the VT in the LV outflow tract, thus avoiding the application of radiofrequency current to valvar leaflets and coronary arteries. Figure 7A–C demonstrates ablation of VT originating from the RV outflow tract. Furthermore, ICE can provide additional information to currently used imaging

Figure 7 (A) Position of catheters as seen on fluoroscopy in a patient with ventricular tachycardia originating from the right ventricular outflow tract (RVOT). (B) ICE image of the same patient, demonstrating the position of the ablation catheter in the RVOT. (C) Electro-anatomical map of the right ventricle (RV) (CARTO). The activation of the RV is colour encoded. Red indicates the area of earliest activation in the RVOT. (D) Imaging in a patient with ventricular tachycardia secondary to ARVD/C. An aneurysmatic area was observed at the inferior part of the RV. Early fragmented signals were recorded at this site during tachycardia and subsequent radiofrequency catheter ablation was initiated at this site. aneur, aneurysm; Ao, aorta; AP, pulmonary artery; cath tip, catheter tip; ICE, intracardiac ultrasound catheter; RA, right atrium; RVA, right ventricular apex.

techniques with regard to tissue characterisation in the diagnosis of ARVD/C[25] (fig 7D). Thus the main value of ICE for guiding VT ablation procedures is threefold: (1) identification of the substrate; (2) monitoring of the position of catheters in relation to cardiac structures, such as valves and coronary arteries; and (3) direct monitoring of procedure related complications.

Other applications
ICE can also be used as a tool to guide diagnostic evaluation of cardiac masses. Using ICE, the extent of the process, its surface and relation to other cardiac structures can be determined. Furthermore, ICE can guide the biopsy needle and monitor acute complications of the biopsy, such as perforation or bleeding.[26] Figure 8 demonstrates an example of an extensive intracardiac mass. In this patient, several biopsies were obtained guided by ICE.

Furthermore, initial results on the use of ICE in balloon mitral valvuloplasty,[27] LAA exclusion,[28] and visualisation of valves in the coronary sinus[29] have been reported. It is in the line of expectations that the applications of ICE will expand in accordance with the expanding experience with percutaneous transcatheter procedures.
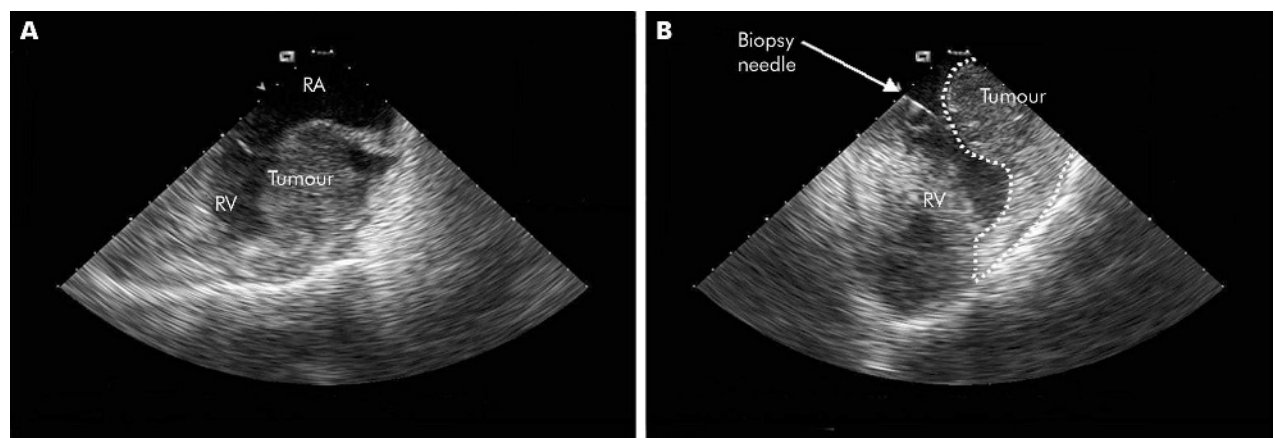
Figure 8 (A) Evaluation of an intracardiac mass by ICE. An extensive mass is present in the right atrium (RA), which extends over the tricuspid annulus to the wall of the right ventricle (RV). (B) Biopsies were taken under ICE guidance. The final diagnosis was B cell non-Hodgkin lymphoma.

Table 2 Advantages of the clinical use of ICE

► Accurate visualisation of intracardiac anatomy that cannot be visualised using fluoroscopy
► Real time visualisation of catheters and intracardiac devices
► Direct monitoring of procedure related complications
► Assessment of haemodynamic function online using Doppler capacities
► Reduction of radiation exposure for patient and operators
► No need for anaesthesia

SUMMARY AND CONCLUSIONS

With the expanding development of percutaneous interventional procedures in the catheterisation laboratory, accurate online identification of intracardiac structures, catheters, and devices is mandatory. At present, the image modality most commonly used in the cath lab is fluoroscopy, which does not allow accurate evaluation of intracardiac structures. Besides TOE, ICE is at present the only imaging modality that can provide this information, combined with haemodynamic information during the procedures. ICE has several clear advantages over the use of TOE, including less patient discomfort and no anaesthesia, thus allowing communication with the patient during the procedure. Recently ICE has been implemented in a growing number of interventional procedures. Advantages of the clinical use of ICE are summarised in table 2.

In conclusion, ICE is a valuable tool for guiding percutaneous interventional procedures, such as transseptal puncture and placement of closure devices. Efficiency is improved in electrophysiological interventional procedures by the ability to identify anatomical structures and integrate this information with electrophysiological information. Furthermore, ICE can be used as a diagnostic tool. Direct detection of intraprocedural complications, such as pericardial effusion and cardiac tamponade, is possible with ICE, allowing immediate intervention. Integration of ICE in procedures is likely to result in reduction of fluoroscopy and procedure times and improved outcome.

. . . .

Authors' affiliations
M R M Jongbloed, M J Schalij, K Zeppenfeld, P V Oemrawsingh, E E van der Wall, J J Bax, Department of Cardiology, Leiden University Medical Center, Leiden, The Netherlands

REFERENCES

1 **Dairywala IT**, Li P, Liu Z, et al. Catheter-based interventions guided solely by a new phased-array intracardiac imaging catheter: in vivo experimental studies. *J Am Soc Echocardiogr* 2002;**15**:150–8.
2 **Chu E**, Fitzpatrick AP, Chin MC, et al. Radiofrequency catheter ablation guided by intracardiac echocardiography. *Circulation* 1994;**89**:1301–5.
3 **Antonielli E**, Pizzuti A, Palinkas A, et al. Clinical value of left atrial appendage flow for prediction of long-term sinus rhythm maintenance in patients with nonvalvular atrial fibrillation. *J Am Coll Cardiol* 2002;**39**:1443–9.
4 **Morton JB**, Sanders P, Sparks PB, et al. Usefulness of phased-array intracardiac echocardiography for the assessment of left atrial mechanical ''stunning'' in atrial flutter and comparison with multiplane transesophageal echocardiography. *Am J Cardiol* 2002;**90**:741–6.
► This paper demonstrates that phased array ICE can be a good alternative to TOE for the evaluation of left atrial mechanical function.
5 **Thakur RK**, Klein GJ, Yee R, et al. Embolic complications after radiofrequency catheter ablation. *Am J Cardiol* 1994;**74**:278–9.
6 **Kok LC**, Mangrum JM, Haines DE, et al. Cerebrovascular complication associated with pulmonary vein ablation. *J Cardiovasc Electrophysiol* 2002;**13**:764–7.
7 **Lundqvist C**, Olsson SB, Varnauskas E. Transseptal left heart catheterization: a review of 278 studies. *Clin Cardiol* 1986;**9**:21–6.
8 **Epstein LM**, Smith T, TenHoff H. Nonfluoroscopic transseptal catheterization: safety and efficacy of intracardiac echocardiographic guidance. *J Cardiovasc Electrophysiol* 1998;**9**:625–30.
9 **Bartel T**, Konorza T, Arjumand J, et al. Intracardiac echocardiography is superior to conventional monitoring for guiding device closure of interatrial communications. *Circulation* 2003;**107**:795–7.
► In this study the value of ICE for guiding ASD closure is described and several advantages as compared to conventional monitoring with TOE are reported.
10 **Earing MG**, Cabalka AK, Seward JB, et al. Intracardiac echocardiographic guidance during transcatheter device closure of atrial septal defect and patent foramen ovale. *Mayo Clin Proc* 2004;**79**:24–34.
► An illustrative report of the extensive experience of the Mayo Clinic with ASD closure guided by ICE.
11 **Ewert P**, Berger F, Daehnert I, et al. Transcatheter closure of atrial septal defects without fluoroscopy: feasibility of a new method. *Circulation* 2000;**101**:847–9.
12 **Haissaguerre M**, Jais P, Shah DC, et al. Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. *N Engl J Med* 1998;**339**:659–66.
13 **Jongbloed MR**, Bax JJ, Zeppenfeld K, et al. Anatomical observations of the pulmonary veins with intracardiac echocardiography and hemodynamic consequences of narrowing of pulmonary vein ostial diameters after radiofrequency catheter ablation of atrial fibrillation. *Am J Cardiol* 2004;**93**:1298–302.
14 **Olgin JE**, Kalman JM, Chin M, et al. Electrophysiological effects of long, linear atrial lesions placed under intracardiac ultrasound guidance. *Circulation* 1997;**96**:2715–21.
15 **Marrouche NF**, Martin DO, Wazni O, et al. Phased-array intracardiac echocardiography monitoring during pulmonary vein isolation in patients with atrial fibrillation: impact on outcome and complications. *Circulation* 2003;**107**:2710–6.
► Improved outcome of PV isolation guided by ICE was demonstrated in this study. The authors describe a technique to adjust power settings of radiofrequency energy guided by the visualisation of microbubbles.
16 **Ernst S**, Ouyang F, Goya M, et al. Total pulmonary vein occlusion as a consequence of catheter ablation for atrial fibrillation mimicking primary lung disease. *J Cardiovasc Electrophysiol* 2003;**14**:366–70.
17 **Saad EB**, Cole CR, Marrouche NF, et al. Use of intracardiac echocardiography for prediction of chronic pulmonary vein stenosis after ablation of atrial fibrillation. *J Cardiovasc Electrophysiol* 2002;**13**:986–9.
► In this paper assessment of PV stenosis using ICE are described and acute findings were compared with computed tomographic imaging to assess the predictive value for chronic PV stenosis.
18 **Verma A**, Marrouche NF, Yamada H, et al. Usefulness of intracardiac Doppler assessment of left atrial function immediately post-pulmonary vein antrum isolation to predict short-term recurrence of atrial fibrillation. *Am J Cardiol* 2004;**94**:951–4.
► This report describes the use of ICE to measure LA appendage peak emptying velocity and peak pulmonary vein systolic wave velocity, and the use of this information to predict short term recurrence of atrial fibrillation after ablation.
19 **Ren JF**, Marchlinski FE, Callans DJ. Left atrial thrombus associated with ablation for atrial fibrillation: identification with intracardiac echocardiography. *J Am Coll Cardiol* 2004;**43**:1861–7.
► Left atrial thrombus may develop during catheter ablation. The authors describe how thrombus may be successfully withdrawn from the LA under ICE guidance.
20 **Olgin JE**, Kalman JM, Fitzpatrick AP, et al. Role of right atrial endocardial structures as barriers to conduction during human type I atrial flutter. Activation and entrainment mapping guided by intracardiac echocardiography. *Circulation* 1995;**92**:1839–48.

989

Intracardiac echocardiography (ICE): key points

► ICE is a promising technique to accurately visualise intracardiac structures that cannot be visualised using only fluoroscopy, without the need for anaesthesia
► Phased array ICE of the whole heart is performed via a percutaneous approach, with an ICE catheter positioned exclusively in the right atrium (RA) or right ventricle (RV)
► Currently, the application of ICE has expanded to several percutaneous interventional procedures. ICE facilitates these procedures by providing online information of intracardiac structures in relation to catheters, puncture needles, and devices
► Limitations of phased array ICE are the inability to scan in a multiplane fashion and the high cost of the single use catheter
► The implementation of standard views of imaging planes may further expand the clinical use of ICE
► The effect of ICE on fluoroscopy and procedure times needs to be established by randomised controlled studies

► This report describes an electro-anatomical correlation of right atrial structures involved in the atrial flutter circuit.

21 **Chu E**, Kalman JM, Kwasman MA, *et al.* Intracardiac echocardiography during radiofrequency catheter ablation of cardiac arrhythmias in humans. *J Am Coll Cardiol* 1994;**24**:1351–7.

22 **Callans DJ**, Ren JF, Narula N, *et al.* Effects of linear, irrigated-tip radiofrequency ablation in porcine healed anterior infarction. *J Cardiovasc Electrophysiol* 2001;**12**:1037–42.

23 **Jongbloed MR**, Bax JJ, van der Burg AE, *et al.* Radiofrequency catheter ablation of ventricular tachycardia guided by intracardiac echocardiography. *Eur J Echocardiogr* 2004;**5**:34–40.

24 **Lamberti F**, Calo' L, Pandozi C, *et al.* Radiofrequency catheter ablation of idiopathic left ventricular outflow tract tachycardia: utility of intracardiac echocardiography. *J Cardiovasc Electrophysiol* 2001;**12**:529–35.

► This report describes the application of ICE to guide radiofrequency catheter ablation of ventricular tachycardia.

25 **Peters S**, Brattstrom A, Gotting B, *et al.* Value of intracardiac ultrasound in the diagnosis of arrhythmogenic right ventricular dysplasia-cardiomyopathy. *Int J Cardiol* 2002;**83**:111–7.

26 **Segar DS**, Bourdillon PD, Elsner G, *et al.* Intracardiac echocardiography-guided biopsy of intracardiac masses. *J Am Soc Echocardiogr* 1995;**8**:927–9.

27 **Salem MI**, Makaryus AN, Kort S, *et al.* Intracardiac echocardiography using the AcuNav ultrasound catheter during percutaneous balloon mitral valvuloplasty. *J Am Soc Echocardiogr* 2002;**15**:1533–7.

28 **Nakai T**, Lesh MD, Gerstenfeld EP, *et al.* Percutaneous left atrial appendage occlusion (PLAATO) for preventing cardioembolism: first experience in canine model. *Circulation* 2002;**105**:2217–22.

► In this report, a new promising percutaneous technique is described for occlusion of the LAA, a known source of embolism.

29 **Cohen TJ**, Juang G. Utility of intracardiac echocardiography to facilitate transvenous coronary sinus lead placement for biventricular cardioverter-defibrillator implantation. *J Invasive Cardiol* 2003;**15**:685–6.

990

MULTIPLE CHOICE QUESTIONS

Education in Heart Interactive (www.heartjnl.com/misc/education.shtml)

There are six multiple choice questions associated with each *Education in Heart* article (these questions have been written by the authors of the articles). Each article is submitted to EBAC (European Board for Accreditation in Cardiology; www.ebac-cme.org) for 1 hour of external CPD credit.

How to find the MCQs: Click on the Online Learning: [Take interactive course] link on the table of contents for the issue online or on the *Education in Heart* collection (www.heartjnl.com/cgi/collection/heart_education).

Free access: This link will take you to the BMJ Publishing Group's online learning website. Your *Heart Online* user name and password will be recognised by this website. As a *Heart* subscriber you have free access to these MCQs but you must register on the site so you can track your learning activity and receive credit for completed courses.

How to get access: If you have not yet activated your *Heart Online* access, please do so by visiting http://www.bmjjournals.com/cgi/activate/basic and entering your six digit (all numeric) customer number (found above your address label with your print copy). If you have any trouble activating or using the site please contact subscriptions@bmjgroup.com

Case based Heart: You might also be interested in the interactive cases published in association with *Heart* (http://cpd.bmjjournals.com/cgi/hierarchy/cpd_node;CBH)